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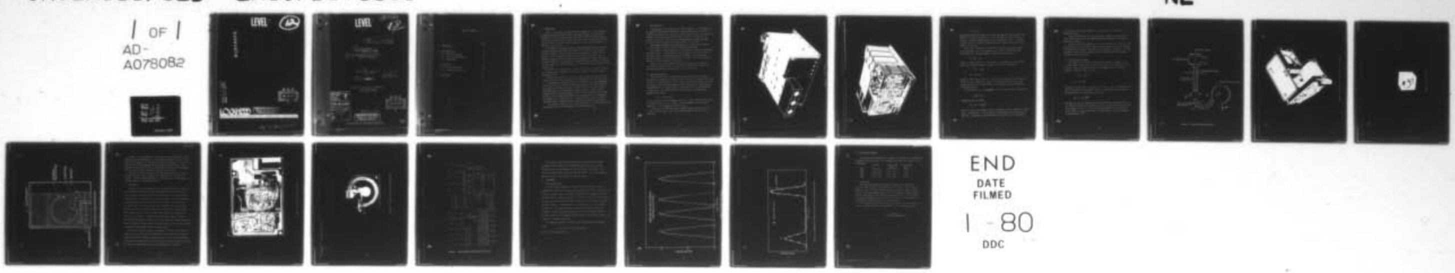

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C IONOPHERIC-MAGNETOSPHERIC PLASMA EXPERIMENT (IMPE).

10 PREPARED BY E. G. SHELLEY

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LOCKHEED PALO ALTO RESEARCH LABORATORY
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1. INTRODUCTION

This is a contract to design, fabricate, assemble, test and integrate The an Ionospheric-Magnetospheric Plasma Experiment (IMPE). The experiment consists of three mass spectrometers covering the energy per charge range from 500 eV to 16 KeV and the mass range from 1 AMU to greater than 150 AMU plus four electron spectrometers covering the energy range from approximately 70 eV to 24 KeV.

The experiment conceptual design, which was adapted from previous ONR sponsored spectrometers which were designed and fabricated by the Space Sciences Laboratory of the Lockheed Palo Alto Research Laboratories, was carried out in the period between December 1974 and March 1975. The detailed design effort was completed in September 1975 at which time fabrication was started. Fabrication was completed by December 1976. Testing at the instrument level was accomplished in the period between December 1976 and December 1977.

The IMPE was integrated into the ARPA 301 payload as the MPA-002 prior to the integration of ARPA-301 with the spacecraft. The latter began in about March 1978.

The IMPE instrument was returned to LPARL in December 1978 for flight sensor installation and was subsequently reintegrated into the spacecraft.

The spacecraft, designated STP 78-1 (2265), was launched ~~from the WIR~~ on 24 February 1979 into a low altitude polar orbit. The IMPE instrument was turned on for full checkout on 2 March 1979. On the basis of quick look data received at the satellite control facility, we were able to determine from the analog monitors that all of the experiment high voltage systems were operating as expected. Those data, however, are inadequate for evaluation of scientific data. It will not be possible to perform a meaningful science evaluation until we receive the digitized data tapes.

The primary utilization of the IMPE data will be in coordinated studies with data from the SC-8 experiment on the SCATHA spacecraft.

2. INSTRUMENTATION

A photograph of the instrument is shown in Figure 1. The combined set of electron spectrometers and ion mass spectrometers together with all associated electronics is contained within this one package. The package is mounted to the spacecraft via the flanges visible at the bottom of the package on both ends. All electrical communication with the spacecraft is via the single connector on the upper right of the figure.

The package dimensions are approximately 4.5 inches by 8.5 inches by 9.5 inches and the total weight is approximately 14 pounds.

The protrusion in the upper left of the figure is the mass spectrometer collimation unit. The rectangular elements within the black circles are the three ion mass spectrometer entrance apertures. The four smaller circular apertures in the lower right of the figure are the entrance apertures for the four electron spectrometers.

Figure 2 shows the instrument with the electronics cover removed. The digital electronics unit is located in the foreground. Some of the electron spectrometer electronics can be seen to the left.

2.1 Mass Spectrometers

A schematic of one of the mass spectrometers is shown in Figure 3. Following a collimation system which limits the range of incident directions visible to the spectrometer, the ions enter a Wein filter (velocity filter). This filter consists of electrostatic fields and magnetic fields directed perpendicular to the incident ion velocity vector and also perpendicular to each other. The forces acting on an ion in such a crossed field geometry are given by,

$$(1) \quad F = q(\varepsilon - \frac{\upsilon B}{c});$$

where q is the electrical charge on the ion, ε is the electrostatic field in statvolts per cm, υ/c is the ion velocity divided by the velocity of light and B is the magnetic field in Gauss.

If an ion is to pass through the system without deflection, the net force F must be zero. Thus, only those ions with velocity near υ_T, such that

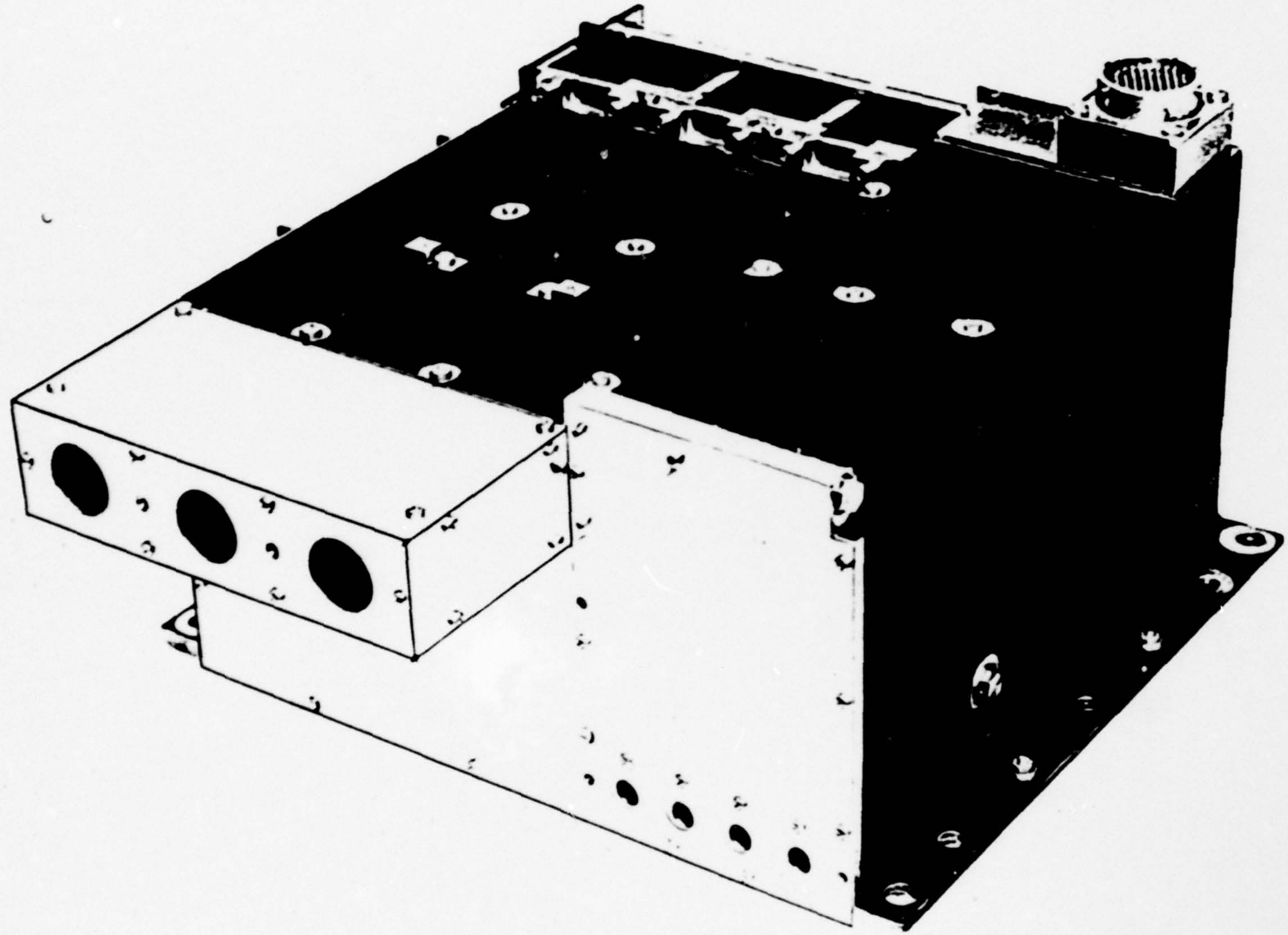


Figure 1. The Instrument

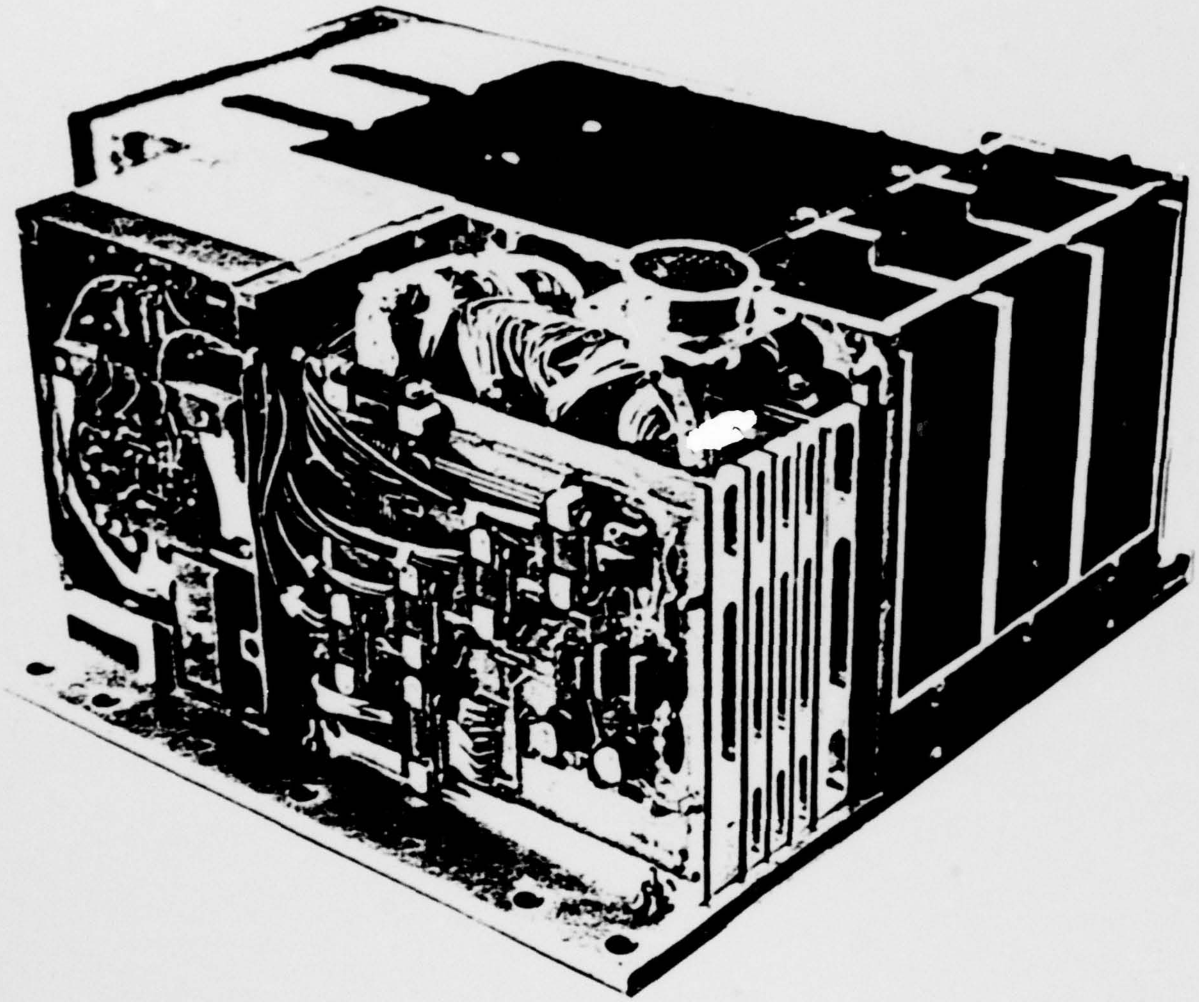


Figure 2. Instrument With Electronics Cover Removed

$$(2) \quad \upsilon_T = \frac{c\epsilon}{B}$$

are passed through the filter. All other ions are deflected to one of the walls of the filter and are lost. If B is fixed, one notes that the velocity is directly proportional to the electrostatic field. Thus the velocity filter is "tuned" by the electrostatic potentials applied to the plates of the filter.

Those ions exiting the velocity filter enter the spherical electrostatic analyzer. Here the trajectory of the ions is determined by the centrifugal force balanced against a radial electrostatic force.

$$(3) \quad \frac{M\upsilon^2}{R} = q\epsilon'$$

where M is the ion mass, R is the radius of the analyzer, and the other symbols are as defined above. Equation (3) can be transformed to

$$\frac{M\upsilon^2}{2} = qR\epsilon'$$

or

$$(4) \quad E/q = R\epsilon'$$

where E is the energy of the ion. Thus, the electrostatic analyzer passes an ion of a given energy per charge. As with the velocity filter, the energy analyzer can be "tuned" by the electrostatic potentials applied to the analyzer plates.

If we substitute υ_T from equation (2) for υ in equation (3), we obtain

$$\frac{M}{R}\left(\frac{c\epsilon}{B}\right)^2 = q\epsilon'$$

solving for M/q, we obtain

$$(5) \quad M/q = R\epsilon'\left(\frac{B}{c\epsilon}\right)^2$$

Thus we see that the combined analyzers determine both the energy per charge (E/q), see equation 4, and the mass per charge (M/q), see equation 5, of the ions. Furthermore, any combination of E/q and M/q can be selected by

controlling the potentials applied to the two sets of electrostatic deflection plates.

In this analyzer the ions are detected by a channel electron multiplier (CEM) symbolized by the C-shaped element following the electrostatic analyzer in Figure 3.

Figure 4 shows a photograph of one of the electrostatic analyzer section together with its CEM. Figure 5 shows a close-up of the CEM in its package. The metal object provides shielding against penetrating radiation. The ions exiting the electrostatic analyzer enter the CEM through the rectangular opening in the metal shield.

2.2 Electron Spectrometers

A schematic of an electron spectrometer is shown in Figure 6. The electrons enter through a multi-element collimator into the magnetic field section. Within the magnetic field the centrifugal force is balanced against the magnetic force, so that

$$\frac{m\upsilon^2}{r} = \frac{q\upsilon B}{c}$$

$$(6) \quad m\upsilon = \frac{qrB}{c}$$

where all the symbols are as defined in 2.1 above. Thus the electron momentum is determined by the magnetic field B and the radius of curvature r. Equivalently the electron energy is given by

$$(7) \quad E = \frac{1}{2m}\left(\frac{qrB}{c}\right)^2$$

The range of electron energies detected by the CEM is a function of the exit aperture length and placement relative to the entrance aperture as well as the magnetic field B. For a given aperture geometry the energy and energy range are proportional to B^2. The $\Delta E/E$ for the IMPE spectrometers is approximately 1.05.

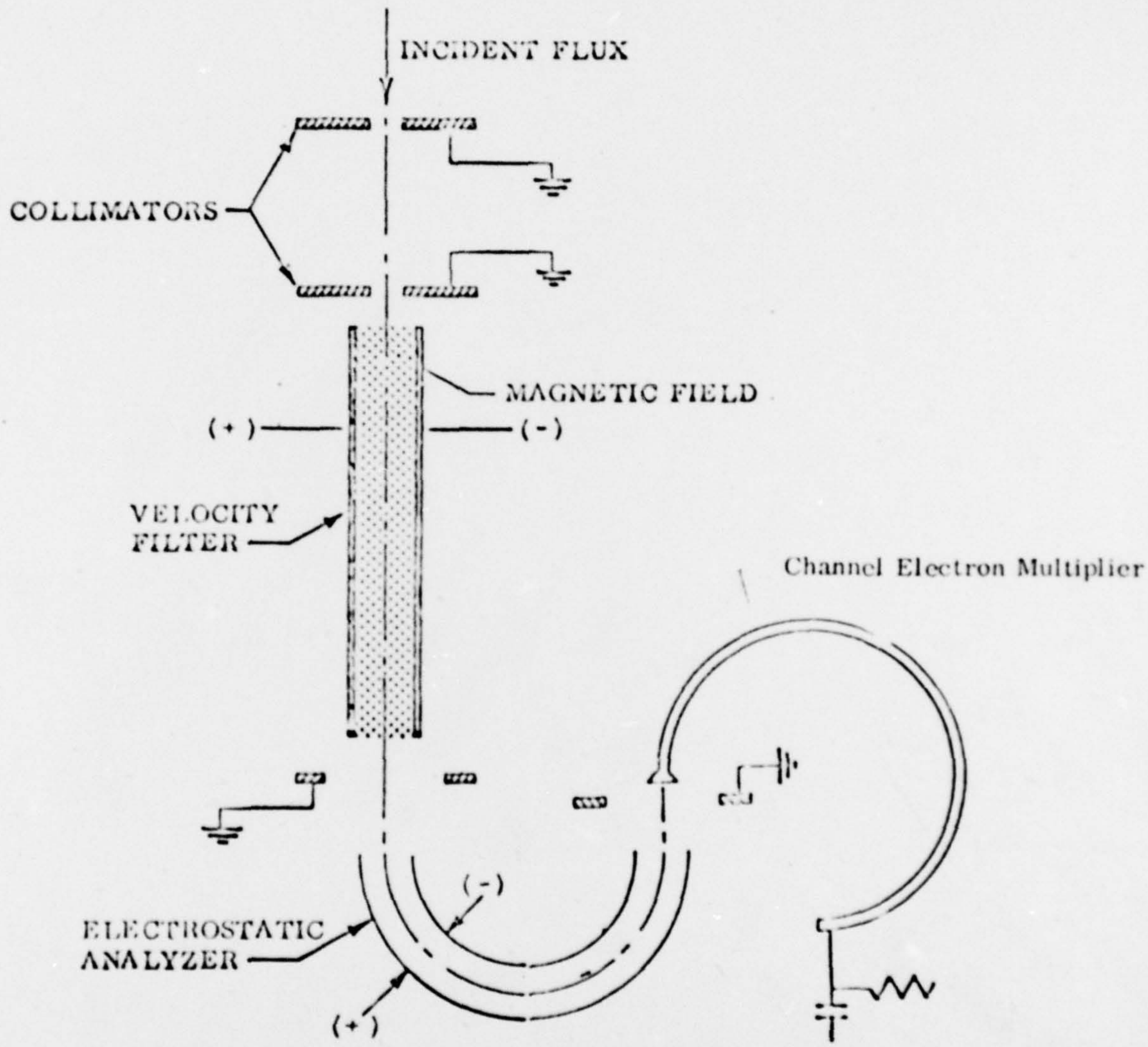


Figure 3. Mass Spectrometer Schematic

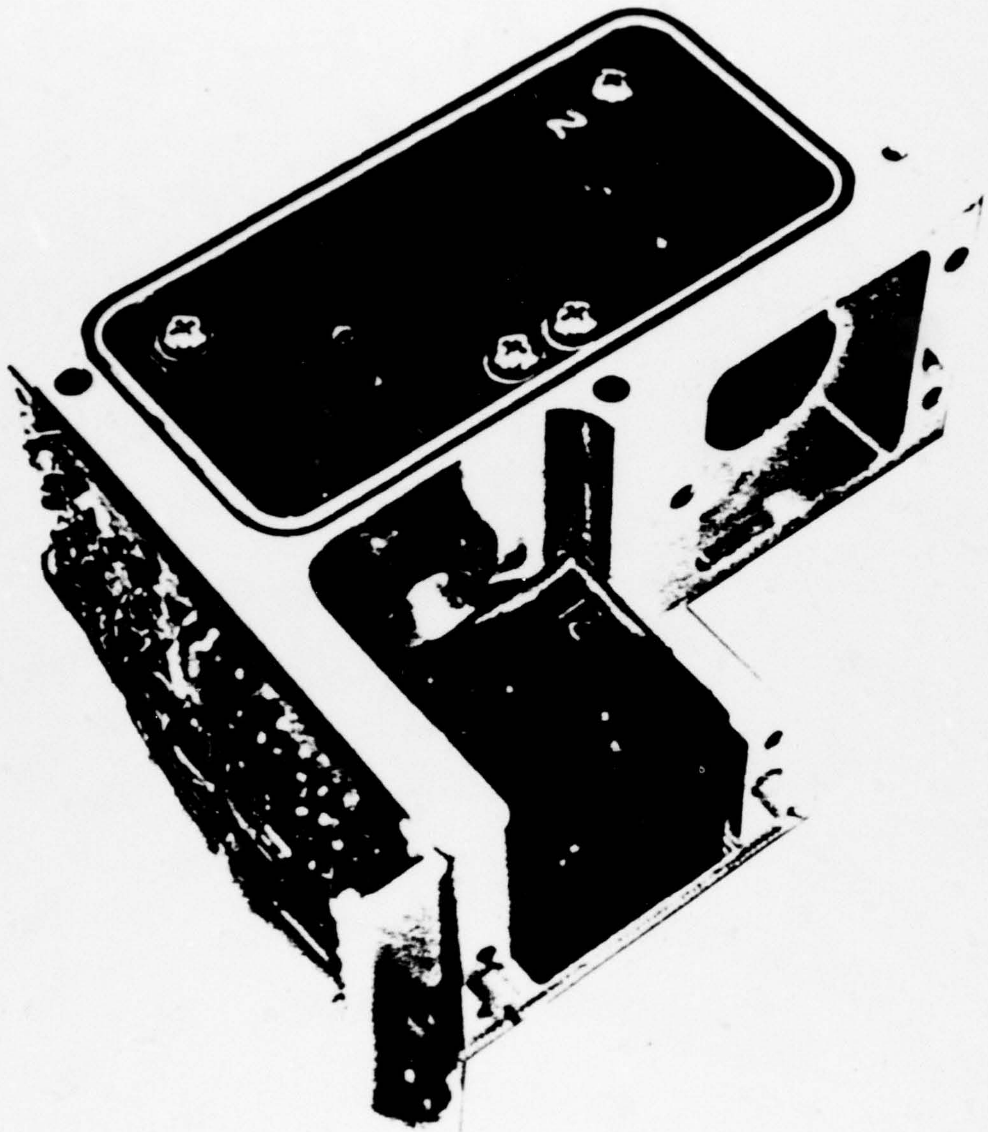
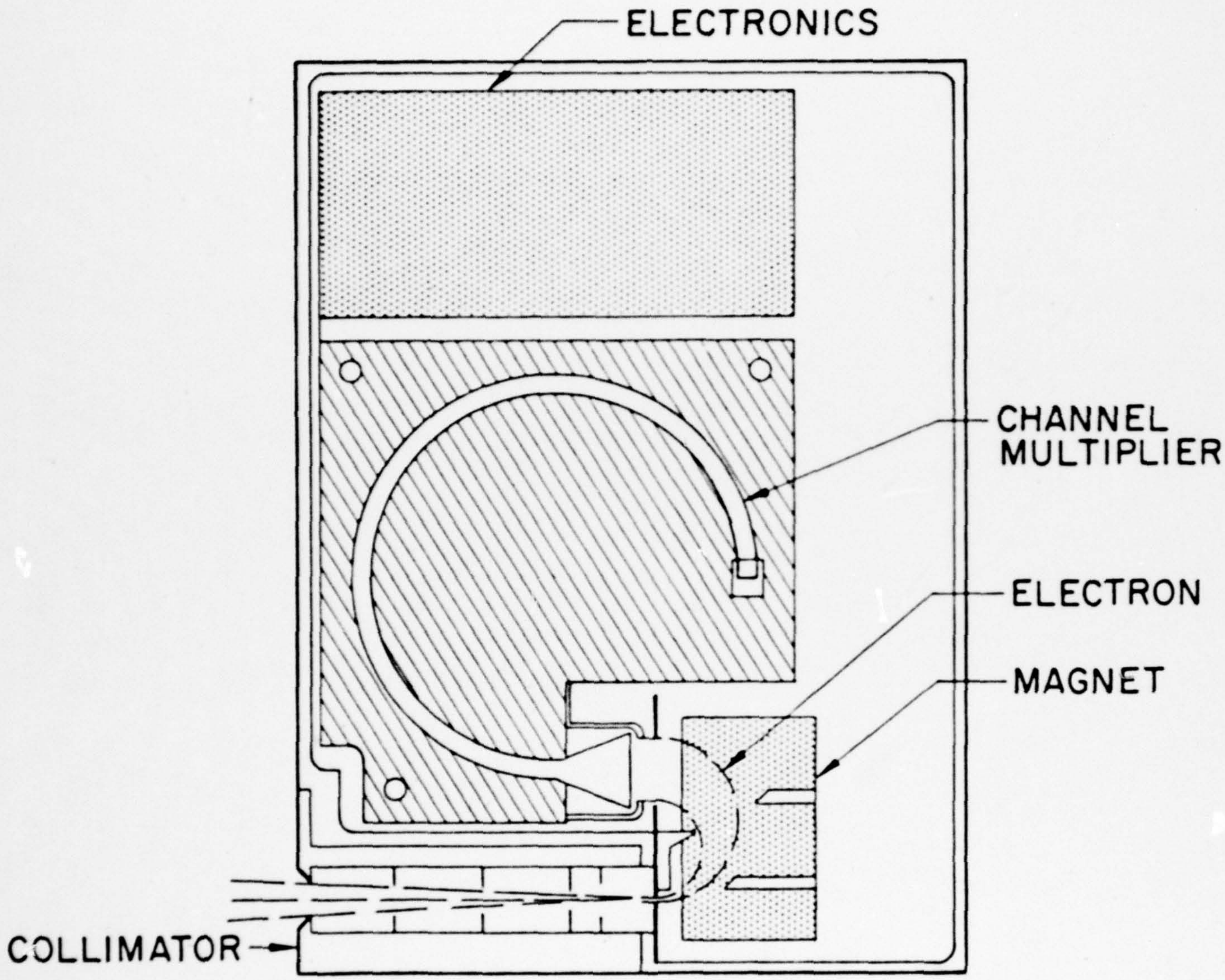


Figure 4. Electrostatic Analyzer Section With Its Cem

Figure 5.   Closeup of Cem



ELECTRON SPECTROMETER

Figure 6. Electron Spectrometer Schematic

Figure 7 is a photograph of one electron spectrometer module with its detector and signal electronics. The entrance collimator is in the lower right and the magnet is in the upper right of the photograph. One can see the front of the CEM extending out from beneath the electronics. Each electron spectrometer with its own preamplifier, amplifier and discriminator is contained within a module as shown in the photograph.

Figure 8 shows the channel electron multiplier (CEM) in more detail. The high voltage blocking capacitor and signal pick-off resistor are visible. The metal wrapping around the front section of the CEM provides shielding against penetrating radiation.

2.3 Electronics

Figure 9 is a block diagram of the instrument electronics. All three mass spectometers are powered by the same Wein Filter (CXA) and electrostatic analyzer (ESA) high voltage power supplies as are all the CEMs. The filter voltages are generated for the highest energy spectometer and divided down appropriately for the lower energy analyzers. The ESA supplies are set on one of four fixed values while the Wein filter supplies ramp once per second over a range of voltages proportional to the square root of the energy setting. The Wein filter ramp voltage can be reduced by a factor of 4 by command. This switches the mass sweep from the normal 1 to $\sim$32 AMU to a range of $\sim$16 AMU to $\gtrsim$ 150 AMU. Additional command selectable modes of operation include locking continously onto a single energy step and cycling more rapidly between only two energy steps.

The CEM bias supply can also be commanded to a higher voltage step to compensate for possible CEM gain degradation. The CEM gain is measured in flight through the in-flight-calibration system. The in-flight-calibration is initiated by command and involves cycling the detector thresholds through four levels to measure the pulse height distribution of the CEMs.

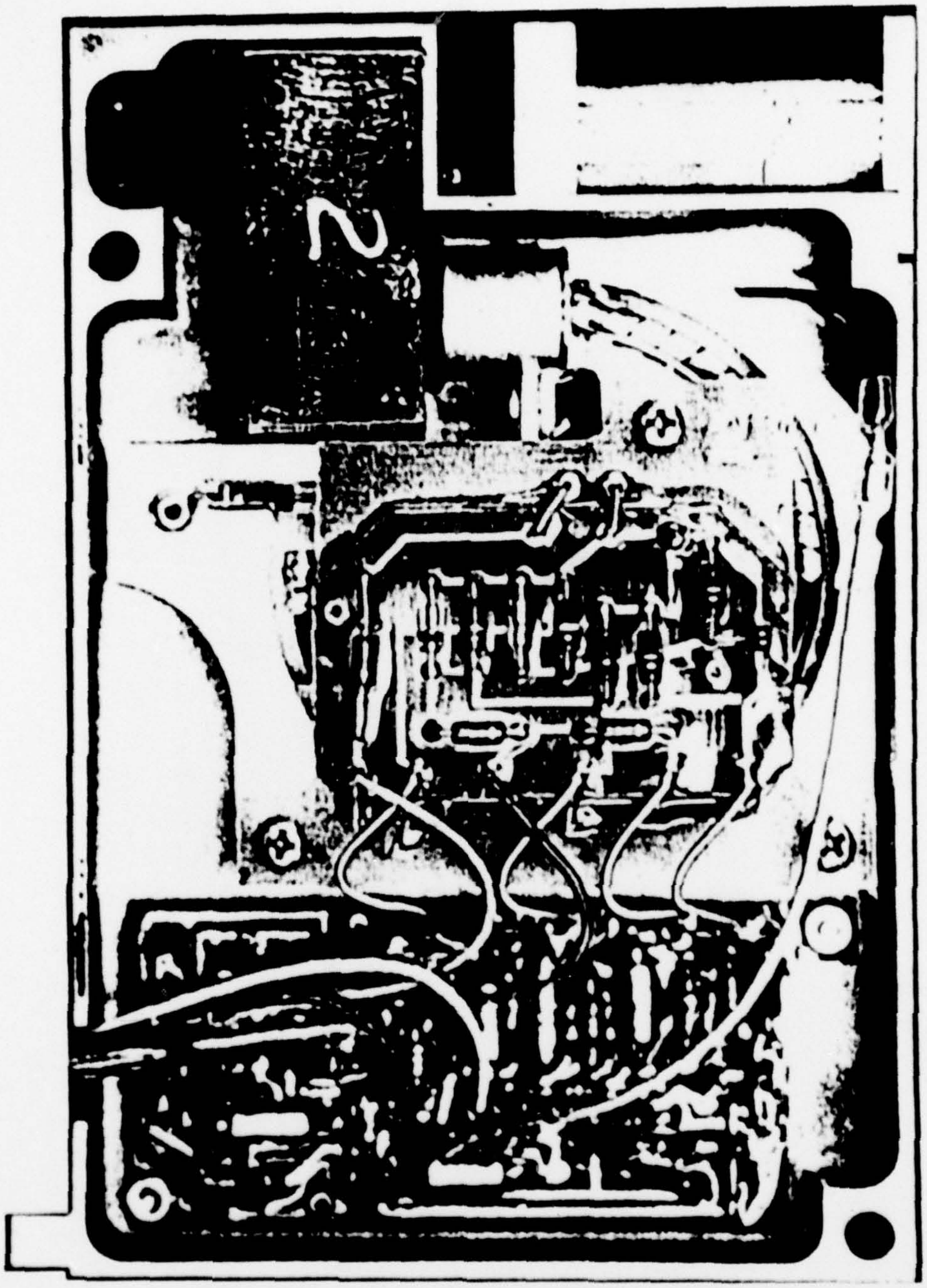


Figure 7. Electron Spectrometer Channel

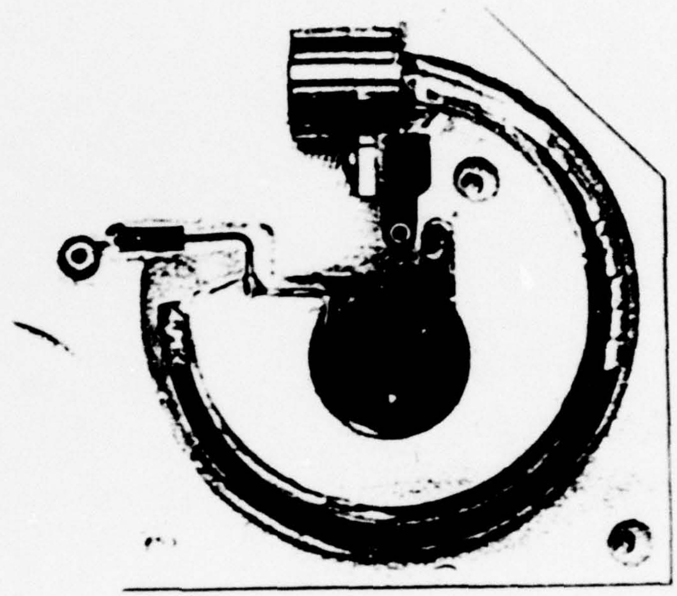


Figure 8. Channel Electron Multiplier Assembly

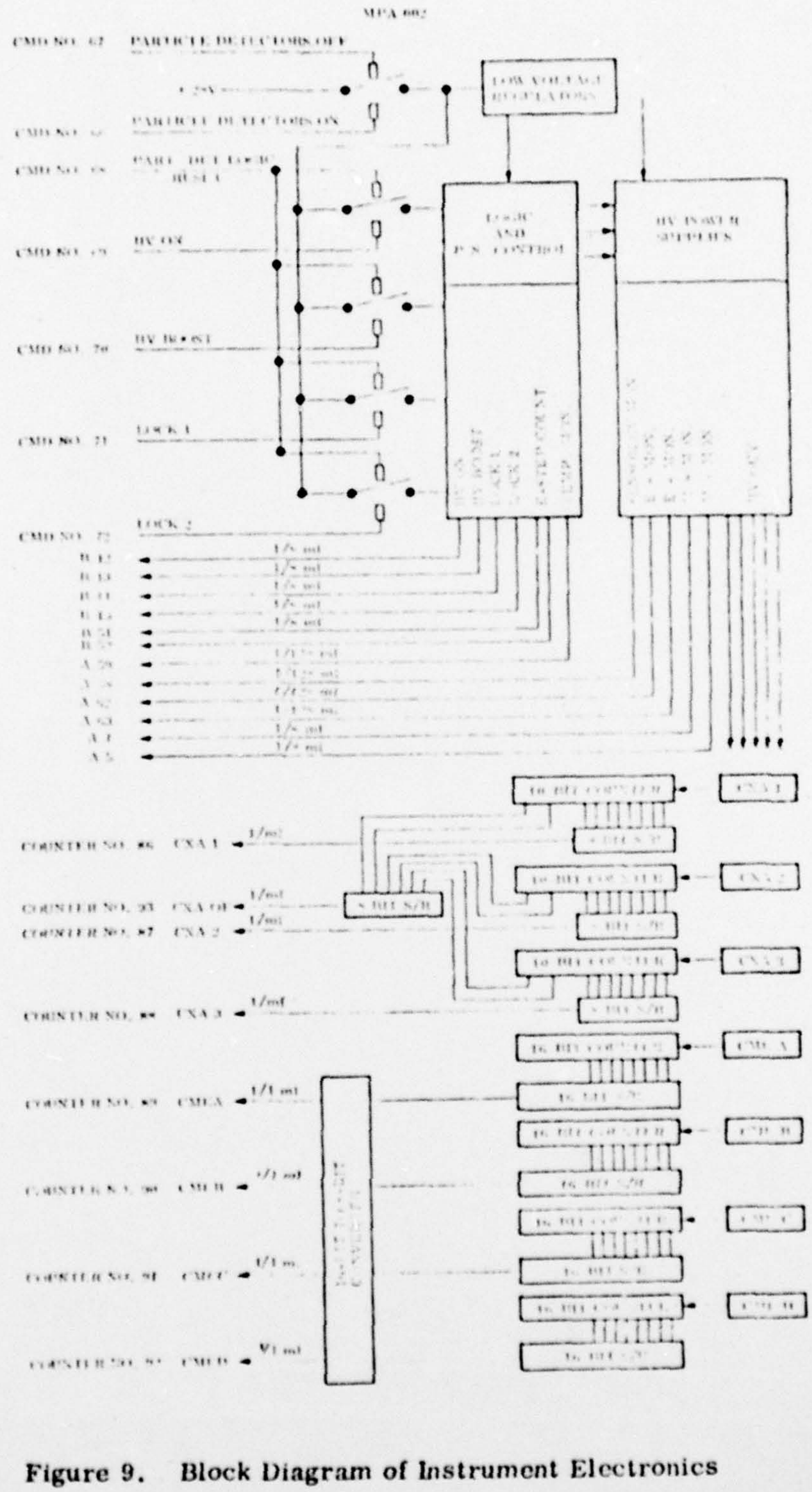


Figure 9. Block Diagram of Instrument Electronics

Data from the three mass spectrometers are accumulated in 10-bit accumulators and transferred to parallel buffers 32 times per second. The buffered data are subsequently read out through the interface. The electron channels (CMEA, CMEB, CMEC and CMED) each feed 16-bit accumulators which are read out via telemetry 8 times per second.

3. CALIBRATION

3.1 Mass Spectrometers

The pre flight calibration of Wein filter spectrometers consists of combined laboratory beam calibration and computer ray tracing. The expected locations of mass peaks as a function of magnetic and electrostatic fields were determined by directing energetic ions down the center of the collimators of mass spectrometers. The detailed line shapes are predicted by a computer ray trace program. Combining these two we predict the line shapes shown in Figure 10. As discussed earlier, suitable flight data are not yet available to compare them with predictions for this instrument; however, we show in Figure 11 a comparison between predicted and flight observed line shapes for a similar spectrometer.

The absolute geometric factors for the spectrometers was determined to be

$$G \Delta E = 3.8 \times 10^{-5} E \ (\mathrm{cm}^2\text{-ster keV})$$

where E is the energy in keV.

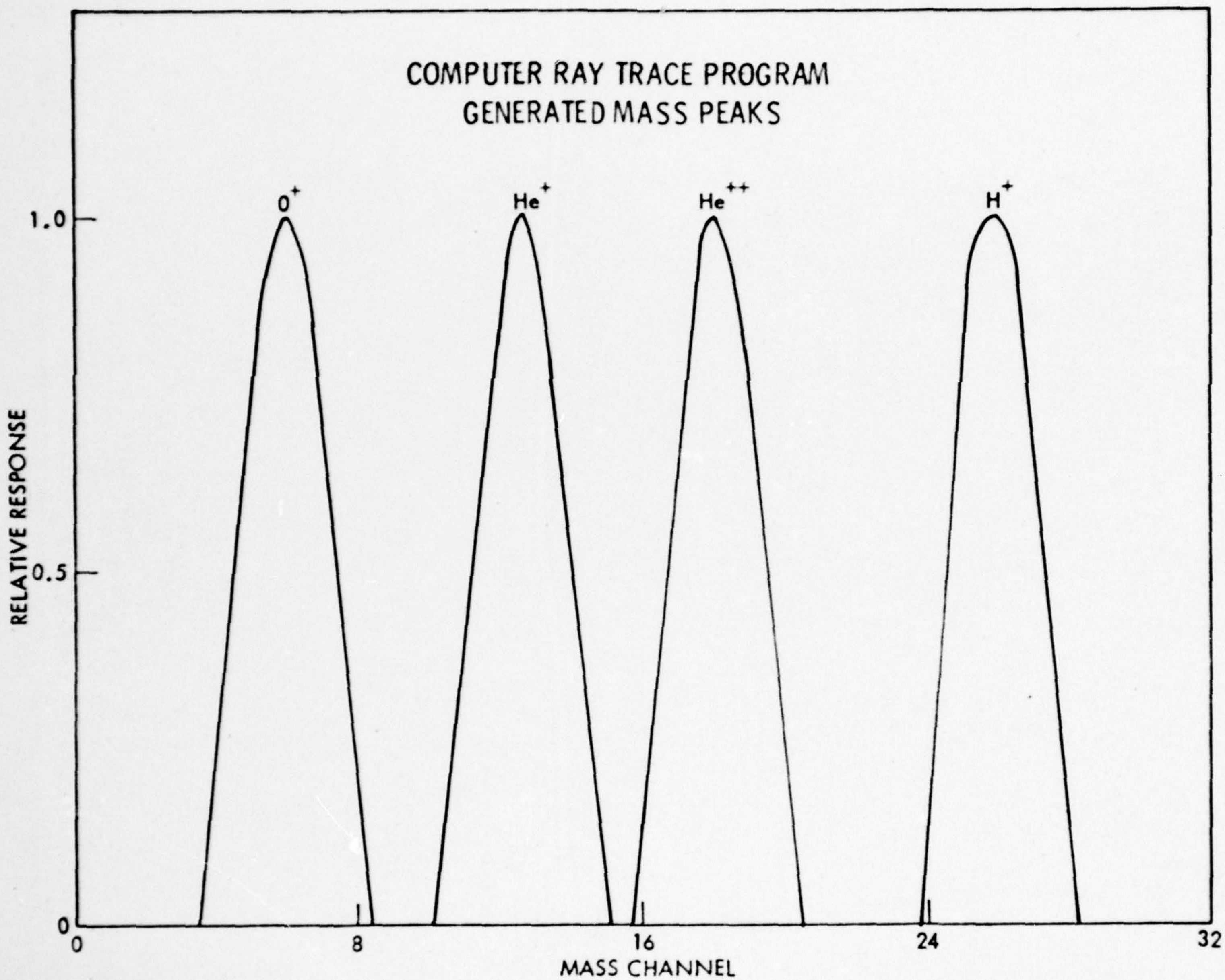


Figure 10. Predicted Line Shapes

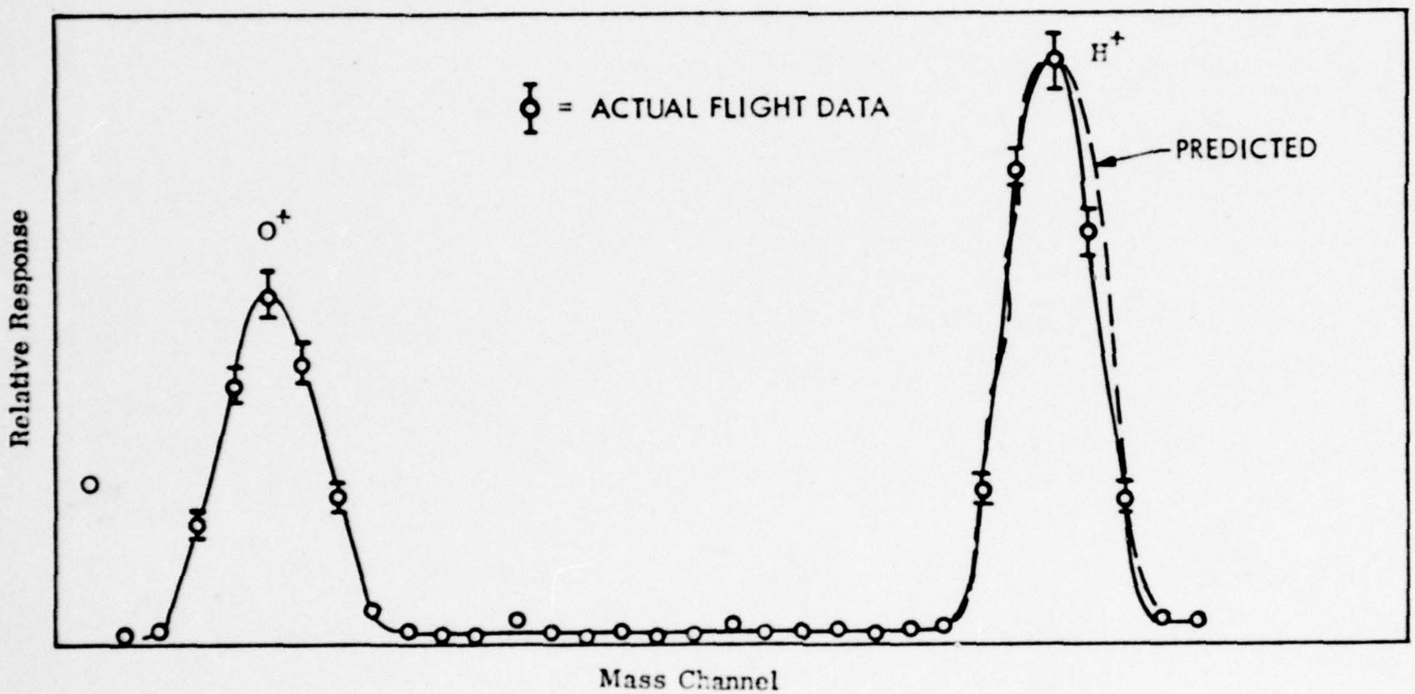


Figure 11. Predicted and Observed Line Shapes for a Similar Spectrometer

3.2 Electron Spectrometer

The electron spectrometers were laboratory calibrated by an absolutely calibrated electron source. The following table shows the results of the calibration.

	$(G\Delta E/E)$	Energy Range (keV)	Center Energy (keV)
CMEA	1.31×10^{5}	0.09 - 0.27	0.18
CMEB	7.58×10^{-6}	0.39 - 1.23	0.84
CMEC	6.98×10^{-6}	1.76 - 5.62	3.86
CMED	4.32×10^{-6}	8.34 -26.72	18.38

4. CONCLUSION

The IMPE spectrometer was launched as MPA-002 of the ARPA-301 payload on the STP 78-1 (2265) satellite on 24 February 1979. On the basis of quick look data available in near real time it was established via the various instrument monitors that the instrument survived launch and all high voltage converters were operating properly. Due to delays in receiving digitized data tapes we do not yet have available data to evaluate the scientific output of the experiment.

It is anticipated that the primary application of the IMPE data will be in coordination with the SC-8 experiment on the SCATHA spacecraft.

E. G. Shelley
Principal Investigator